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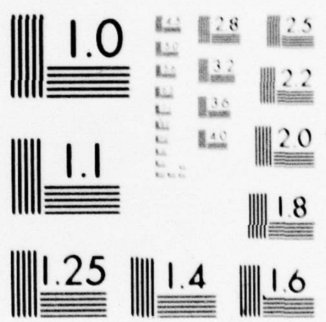

LEVEL II

RESEARCH AND DEVELOPMENT TECHNICAL REPORT
DELNV-TR-79-4

DESIGN APPROACH FOR THE VISIOCEILOMETER AN/GMQ-( ) (XE-1)

Henry Saphow
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Earl Griggs

NIGHT VISION & ELECTRO-OPTICS LABORATORY

September 1979

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This report details the in-house efforts to design, fabricate and test a combination visiometer/ceilometer based upon Laser Rangefinding and CCD technologies. The effort described demonstrated concept feasibility and offers recommendations for implementing future generation equipment.

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AN/GMQ-( )(XE-1)

1. INTRODUCTION

For many operational/tactical applications, a need exists for a practical and affordable device which will determine cloud ceiling and visibility. Specific applications include accurate ceiling and visibility data for forward area landing sites, precision guided munitions (COPPERHEAD) and shipboard applications. A joint development effort was pursued by Night Vision/Electro-Optics (NV&EO), and Atmospheric Sciences Laboratories (ASL) of the US Army Electronics Research and Development Command (USA ERADCOM) to design and fabricate a single-ended transmissometer and ceilometer. The work described in this report constitutes NV&EO Laboratories role in the design, fabrication, and testing of a prototype visibility and ceiling sensor.

2. SYSTEMS CONCEPT

a. General

A Hand-Held Laser Rangefinder (AN/GVS-5) is integrated with a lidar receiver and transient recorder to provide the dual function of measuring visibility and cloud ceiling (visioceilometer). The advantages of the single-ended approach include minimum setup time, capability of measuring slant or horizontal visibility, and the ability to detect atmospheric inhomogenity. Figure 1 depicts the basic modules with their respective characteristics used in the prototype unit. The actual system delivered provides a digitized lidar signal for analysis by mini-computers (provided by ASL), and is shown in Figure 2. The major objectives of this program were to design and fabricate a self-contained, single-ended visibility and ceiling sensor. Additional objectives (present and future) are summarized in Table 1.

Table 1. System objectives.

Self contained;

Man-portable/Hand-held;

Single ended;

Cloud ceiling measurements (0.1-3.0 km);

Slant or horizontal visibility capability;

Availability of non-averaging displays/single reading of information;

Ability to detect inhomogeneity (spatial dynamics);

Ability to update at selectable rate (temporal dynamics);

Maximum use of existing modules in the framework of DOD/Commercial availability for low cost.

CHARACTERISTICS

1.06 μm LASER

SINGLE 6 NANO SEC PULSE

AV ENERGY / PULSE =

12 MILLIJOULES

CLOUD HEIGHT

RANGE = 100m to 3km

VISIBILITY DETECTOR

SENSITIVITY 10 WATTS.

WILL DETECT

BACKSCATTER BEYOND 700 M

IN A 1km VISIBILITY FOG.

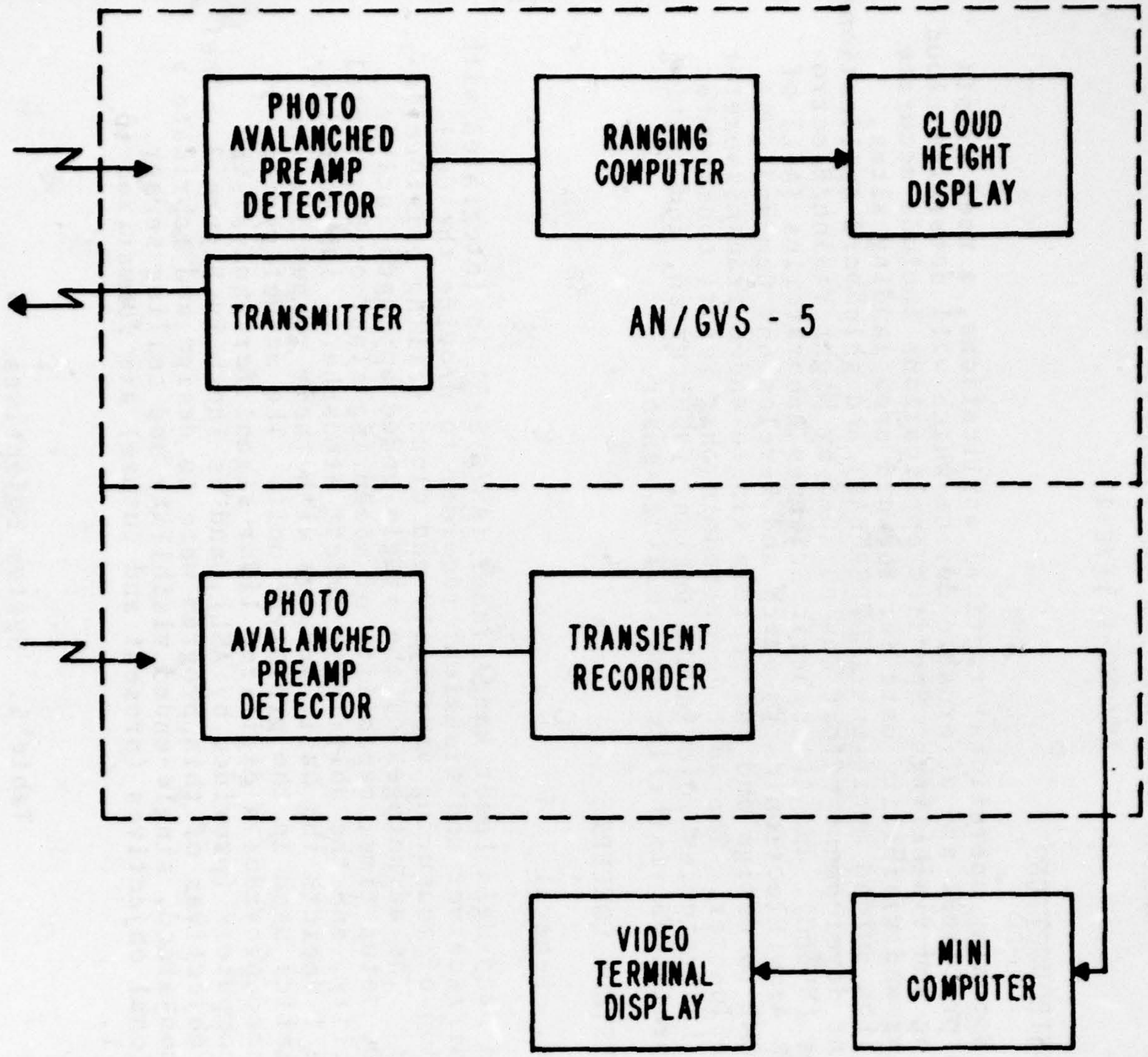

FIGURE 1. EXPERIMENTAL PROTOTYPE VISIOCEILOMETER

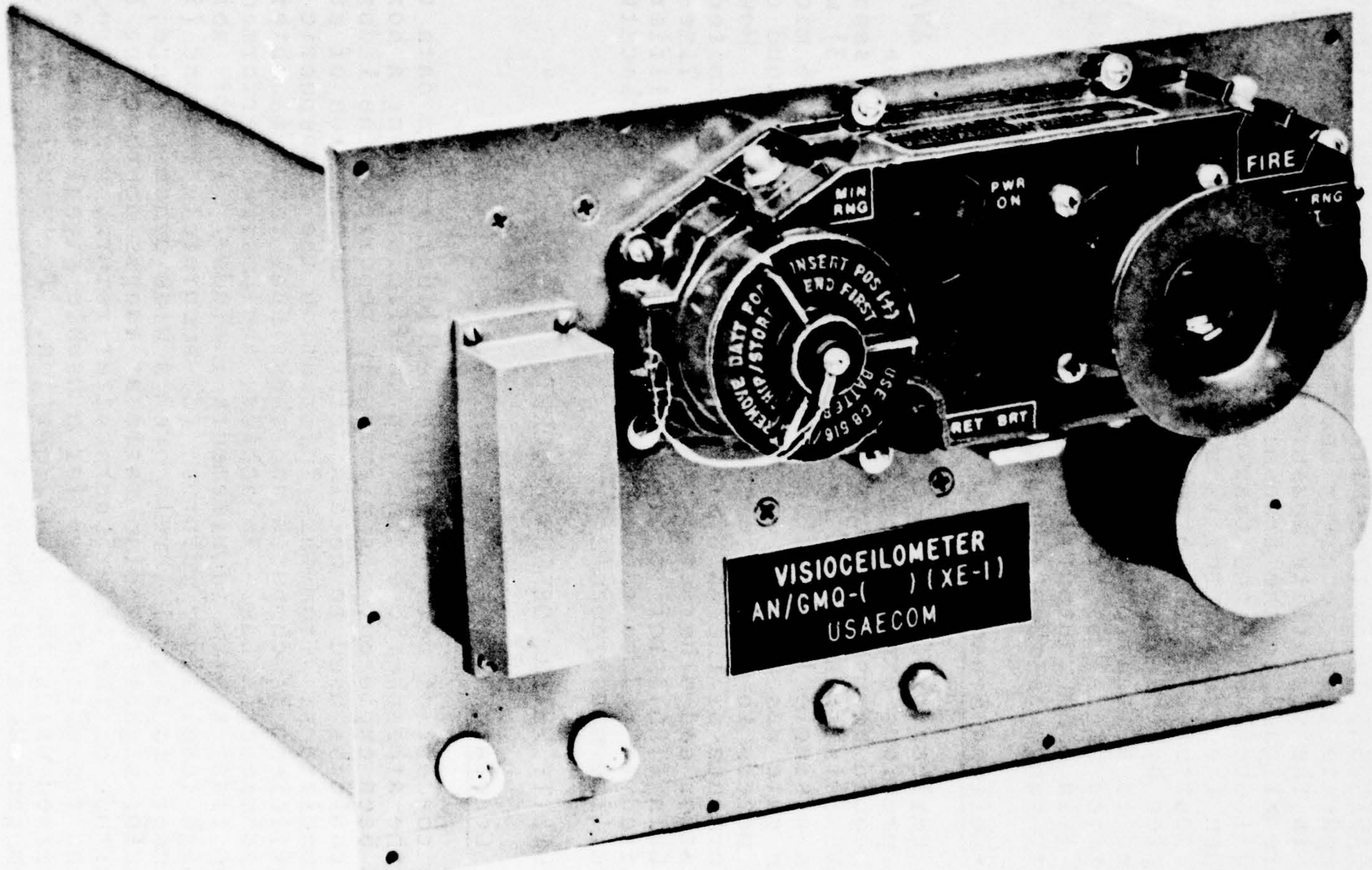

Figure 2. Visioceilometer AN/GMQ-( ) (XE-1).

b. Visibility Sensor

The AN/GVS-5 laser transmitter (common to the ceilometer) with a separate lidar receiver and transient recorder, are utilized in the visibility measurements. The lidar receiver optics are aligned to the transmitter providing a well defined geometrical overlap of the transmitter and receiver field-of-view. When the transmitter is activated, the resultant laser pulse is scattered by the atmosphere. The backscattered portion is collected by the receiver optics. The receiver signal output is applied to a transient recorder to be digitized. The resultant digitized signal is transmitted to a remotely located mini-computer (via a BAC output). With the proper algorithm, the visibility range is then computed.

c. Ceiling Sensor

The ceilometer function is provided by a modified AN/GVS-5. Based on previous experience, it was concluded that the AN/GVS-5 could be used effectively as a cloud ceiling sensor. The AN/GVS-5 is a hand-held laser rangefinder (Figure 3) which transmits a single laser pulse at a wavelength of 1.06 microns. The range gate was minimum was verified to measure cloud ceiling from 100 meters to 9990 meters (10 meter resolution). However, the performance of the AN/GVS-5 as a ceilometer is limited by precipitation and other atmospheric conditions. The Time-Program-Gain (TPG) profile of the AN/GVS-5 video amplifier module was modified to reduce the effects of precipital backscatter during ceiling measurements.

3. VISIBILITY METER, DESIGN CONCEPT

a. General

The concept of using single-ended lidar return data to compute the atmospheric extinction coefficient along a horizontal path has been explored. As previously reported, the lidar returns could be used to obtain detailed information of atmospheric conditions. From this information the atmospheric extinction coefficient is computed and the visual range is obtained using Koschmieder's Law. To achieve the desired performance base, the lidar system requirements include: (1) the ability to handle high level lidar returns; (2) accurately respond (in a known manner) to signal levels over a wide dynamic range; and (3) a useful signal-to-noise ratio at ranges approaching 1 km. The magnitude of the lidar backscatter return, dynamic requirements, and the maximum range for a usable signal-to-noise ratio is determined using the lidar equation. For single scattering and a homogeneous atmosphere, the backscattered power is given by

Figure 3. Hand-held Laser Rangefinder AN/GVS-5.

$$P(R) = E_o Ar \frac{c}{2} B(R)F(R) \frac{\exp(-2\sigma R)}{R^2} \quad (1)$$

where R = distance between receiver and scattering point,

E_o = transmitted energy,

t_p = pulse width,

c = speed of light,

Ar = receiver area,

$B(R)$ = backscatter coefficient,

$F(R)$ = crossover function,

$\sigma(R)$ = extinction coefficient

The field-of-view to beam crossover function is dependent upon the geometrical and operational characteristics of the laser transmitter and lidar receiver. Based upon the system characteristics, the overlap function was computed and is shown in Figure 4. Using Equation (1) and the computer overlap function, backscatter profiles for visibilities of 100 meters and 1000 meters were calculated (see Figure 5) to determine the required lidar receiver operating characteristics. These results are summarized in Table 3 and are used as the basic design specifications.

Table 2. System characteristics.

Transmitter output energy	10 millijoules
Beam divergence	1 milliradians
Receiver diameter	57.15 millimeters
Field-of-view	3 milliradians
Minimum crossover range	50 meters

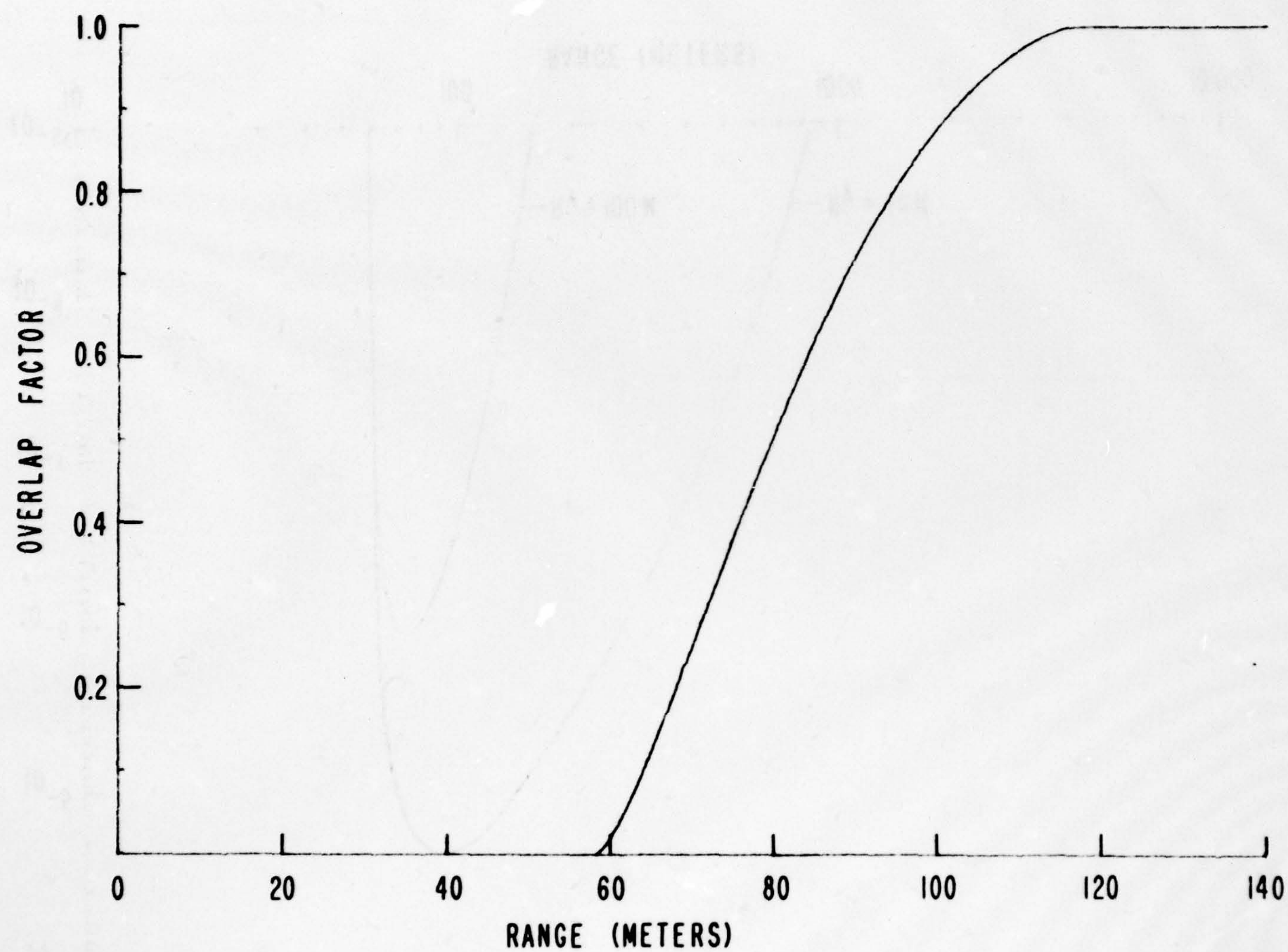

FIGURE 4. VISIO CROSSOVER FUNCTION

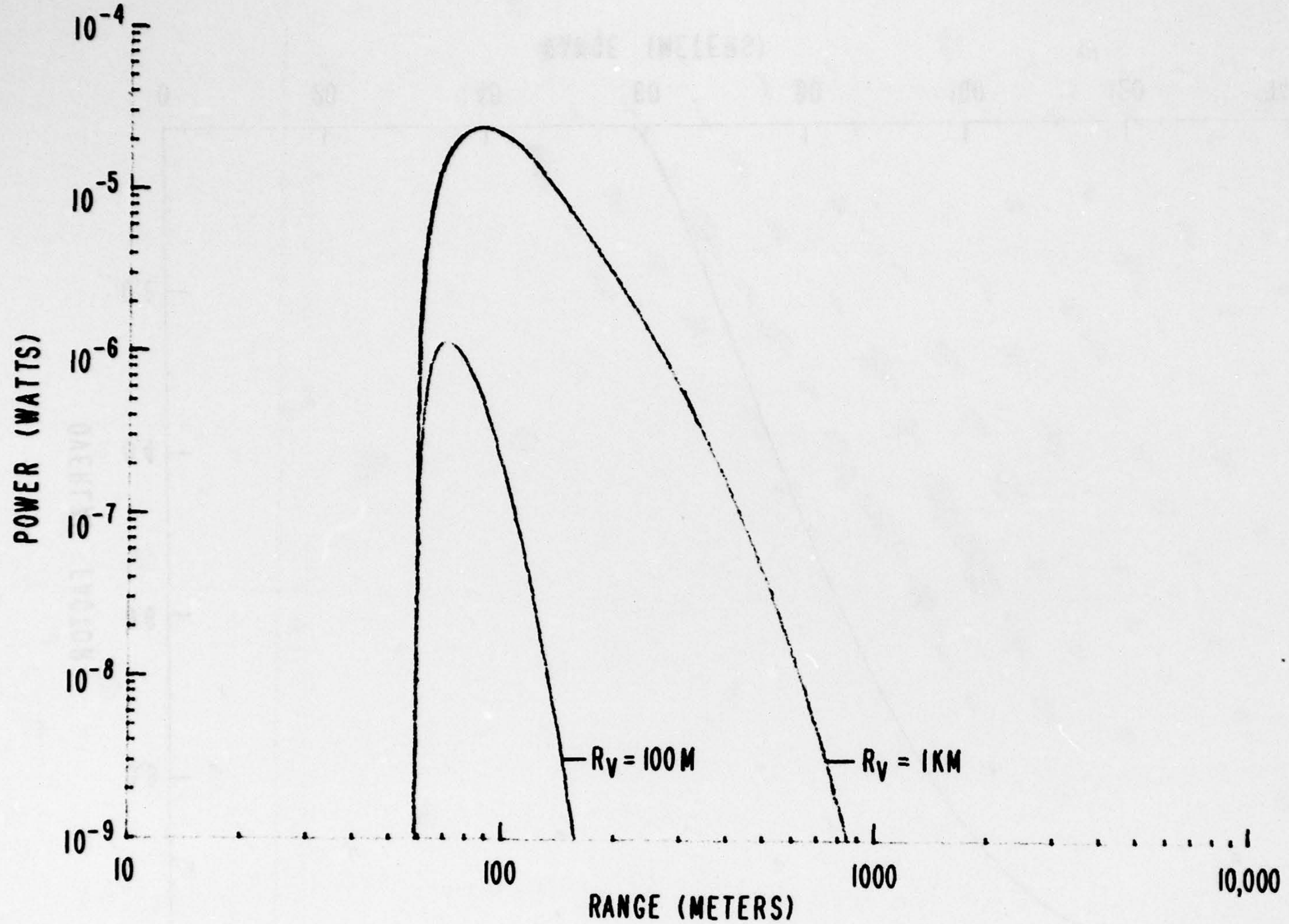

FIGURE 5. BACKSCATTER PROFILE

Table 3. Receiver characteristics.

Psmax (single scattering)	65×10^{-6} watts
Psmin	3×10^{-9} watts
Dynamic range required	> 65 dB
Bandwidth	40 MHz
Video amplifier compression	40 dB
Responsivity (detector-preamp. module)	6×10^{4} volts/watt

The assumption that fogs are totally homogeneous is generally not valid, but may be assumed to be incrementally homogeneous. To account for the inhomogeneity, Equation (1) must be modified to include changes in the atmosphere for each incremental change, resulting in the following:

$$P(r) \Big|_{R_1}^{r_2} = \frac{AP_t t_p CB(R) F(R)}{2R^2} \int_{R_1}^{R_2} e^{-2\sigma(R) dR} \tag{2}$$

b. <u>Hardware Description</u>

The prototype unit consists of a lidar receiver, signal processor (transient recorder), and AN/GVS-5 laser transmitter module. The transmitter generates a laser pulse which is scattered by the atmosphere resulting in a continuous backscatter profile. The lidar backscatter return is detected and amplified by the receiver. The receiver output is coupled to a signal processor unit (SPU) consisting of analog Charge Coupled Device (CCD) and Analog to Digital (A/D) converter. In the SPU, the backscattered signal is sampled, time expanded, and digitized. The processed signal is made available for analysis by a mini-microcomputer. A block diagram is shown in Figure 6.

c. <u>Lidar Receiver</u>

The lidar receiver (see Figure 7) consists of a detector-preamp module, buffer amplifier and a logarithmic amplifier. A sensitive, low-noise lidar receiver capable of responding to large signal levels was required to meet system objectives. A temperature-compensated silicon avalanche photodiode-preamp module was selected which ensures low-level signal detection, while maintaining a constant responsivity independent of ambient

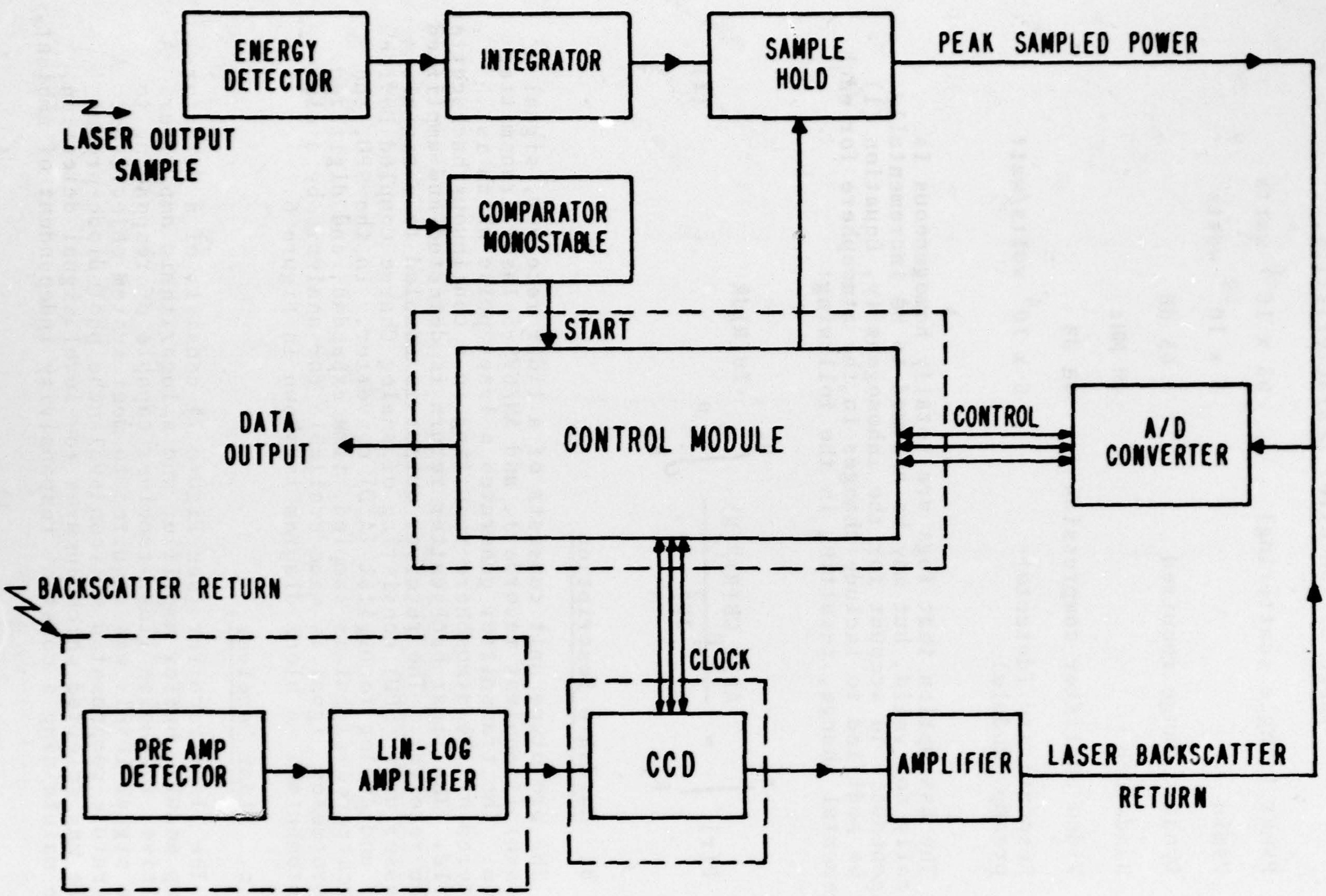

Figure 6. Signal processing block diagram for visioceilometer.

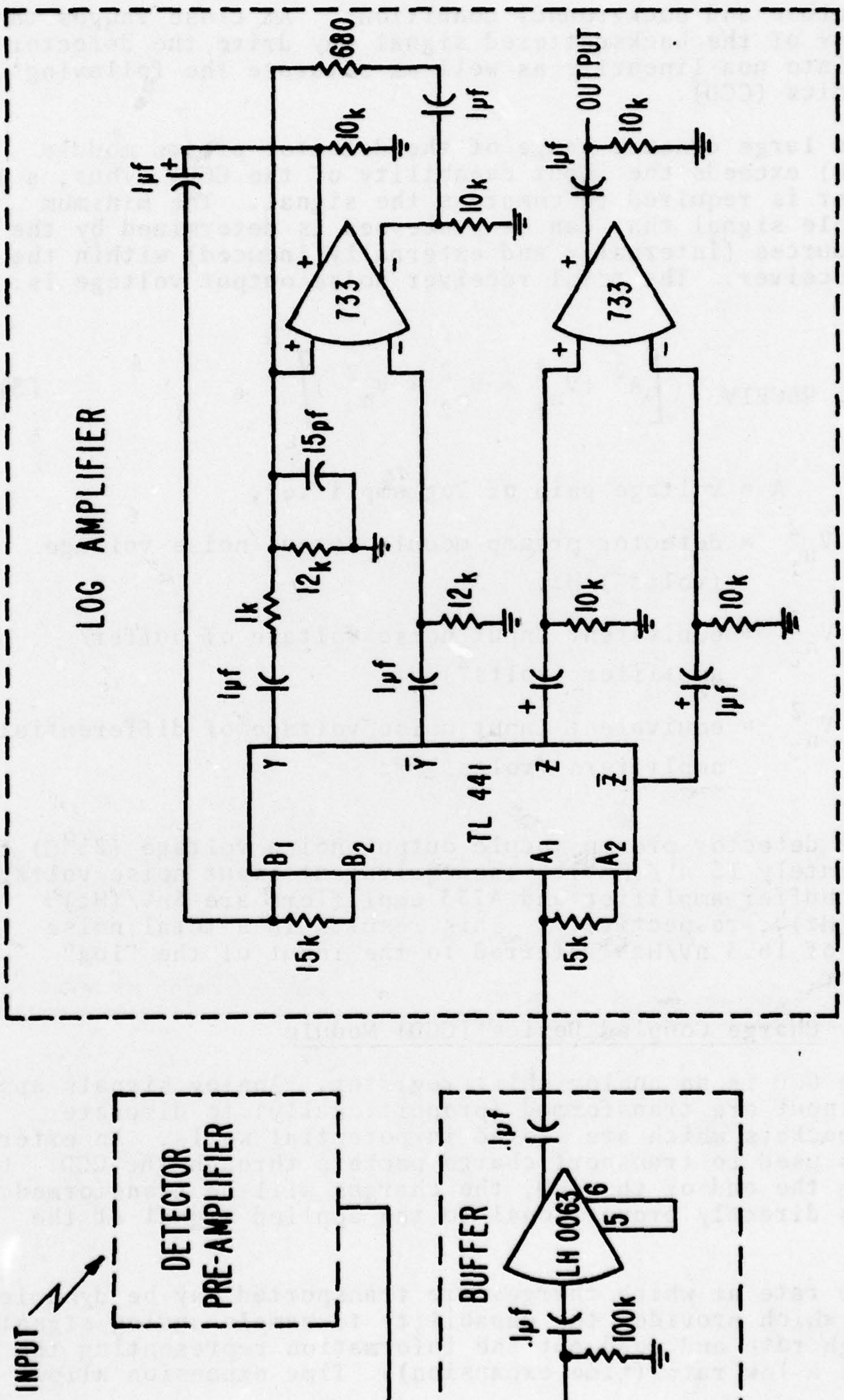

FIGURE 7 VIDEO AMPLIFIER

(temperature and background) conditions. At close ranges the intensity of the backscattered signal may drive the detector-preamp into non-linearity as well as saturate the following electronics (CCD).

The large dynamic range of the detector-preamp module (> 80 dB) exceeds the input capability of the CCD. Thus, a log amplifier is required to compress the signal. The minimum detectable signal that can be processed is determined by the noise sources (internally and externally induced) within the lidar receiver. The total receiver noise output voltage is:

$$V_{n\ RECEIV} = \left[A^2 \left(V_{n_1}^{\ 2} + V_{n_2}^{\ 2} + V_{n_3}^{\ 2} \right) \right]^{\frac{1}{2}} \qquad (3)$$

where

A = voltage gain of log amplifier,

$V_{n_1}^{\ 2}$ = detector-preamp module output noise voltage (volts^2)/Hz,

$V_{n_2}^{\ 2}$ = equivalent input noise voltage of buffer/amplifier (volts^2)/Hz

$V_{n_3}^{\ 2}$ = equivalent input noise voltage of differential amplifiers (volts^2)/Hz

The detector-preamp module output noise voltage (25^{o}C) is approximately 15 nV/(Hz$^{\frac{1}{2}}$). The equivalent input noise voltage for the buffer amplifier and A733 amplifiers are 5nV/(Hz)$^{\frac{1}{2}}$ and 4nV(Hz)$^{\frac{1}{2}}$, respectively. This results in a total noise voltage of 16.3 nV/Hz$^{\frac{1}{2}}$ referred to the input of the "log" amplifier.

d. Charge Coupled Device (CCD) Module

The CCD is an analog shift register. Analog signals applied to the input are transformed (proportionally) to discrete charge packets which are stored in potential wells. An external clock is used to transport charge packets through the CCD. Upon reaching the end of the CCD, the charges will be transformed to voltages directly proportional to the applied signal at the output.

The rate at which charges are transported may be dynamically varied, which provides the capability to sample analog signals at a high rate and read out the information representing the input at a low rate (time expansion). Time expansion allows

signal processing with low speed electronics. The CCD is a complex device which requires several bias voltages and multi-phase clocks for operation.

e. Analog board

The analog board (see Figure 8) is used to sample the laser pulse (providing a start pulse and a measure of output energy) and digitizes the sampled lidar return as it is shifted out of the CCD. The transmitted laser pulse is detected by a PIN photodiode via fiber optics and applied to a high speed comparator which generates the start pulse. The detected signal is also applied (through an integrator) to a peak sample and hold circuit which provides a measure of the laser output energy. The sample and hold circuit output is applied to a 12-bit analog-to-digital converter (A/D) which employs successive approximation with an eight microsecond conversion time. A serial digital output is available for interfacing to either a mini/micro computer. The output of the CCD is digitized by the same A/D converter. The A/D input is sequenced via analog switches, S_2 and S_3. Initially S_2 is closed and S_3 opened, allowing only the sample hold output to be digitized. Upon completion of the first conversion cycle, S_2 is opened and S_3 closed allowing digitization of the CCD output. An additional analog switch S_1(initially opened), is employed at the input of the CCD, with the start pulse closed allowing the backscatter return to be stored in the CCD.

f. Control Module

The Control Module (shown in Figure 9) provides lidar sequencing and clocking. Prior to the start pulse sequencing, all is inhibited, and a 20 megahertz, two-phase clock is applied to the CCD module. The start pulse (obtained from the analog board), initiates control module operation. The first command generated by the control module is to sample and hold the integrated output energy signal and is followed by sequencing commands to the analog switches as previously described. During sequencing the CCD clock drive to the CCD is converted from 20 megahertz to 44 kilohertz. In addition, the control module provides convert commands to the A/D converter until 120 samples of the lidar return are digitized. After 120 samples are digitized, all analog switches are inhibited and the CCD clock is returned to 20 megahertz.

The module is controlled by an 80 megahertz crystal oscillator from which 20 megahertz and 44 kilohertz clocks are obtained. The 20 megahertz clock is obtained using a divide by four counter. This counter normally is active, except for 180 nano-seconds required to synchronize with the laser start signal reducing the uncertainty to $\pm$ 12.5 nanoseconds. The 20 megahertz clock is used to shift data into the CCD. A programmable synchronous counter is used to obtain the 44 kilohertz clock

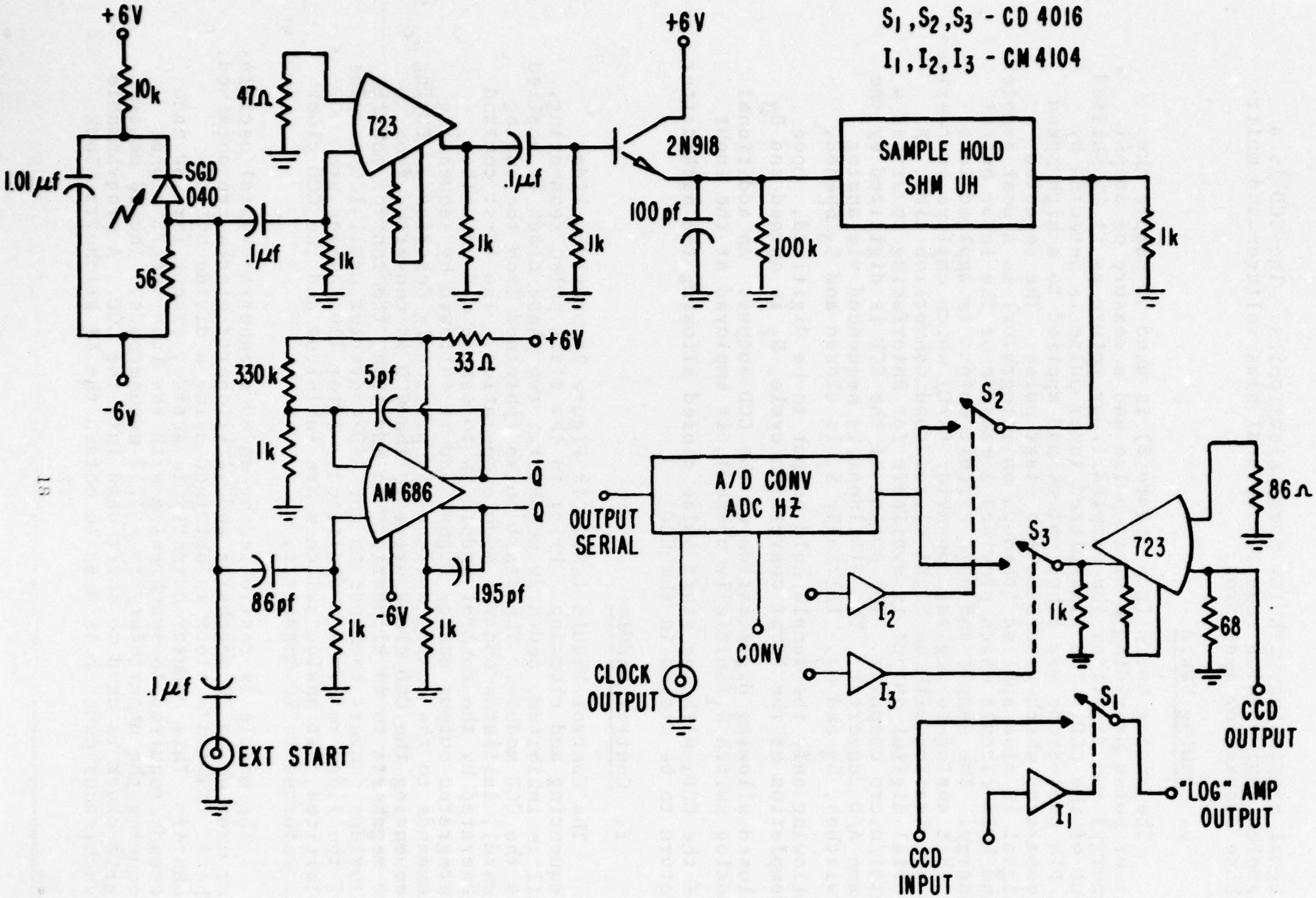

FIGURE 8 ANALOG BOARD

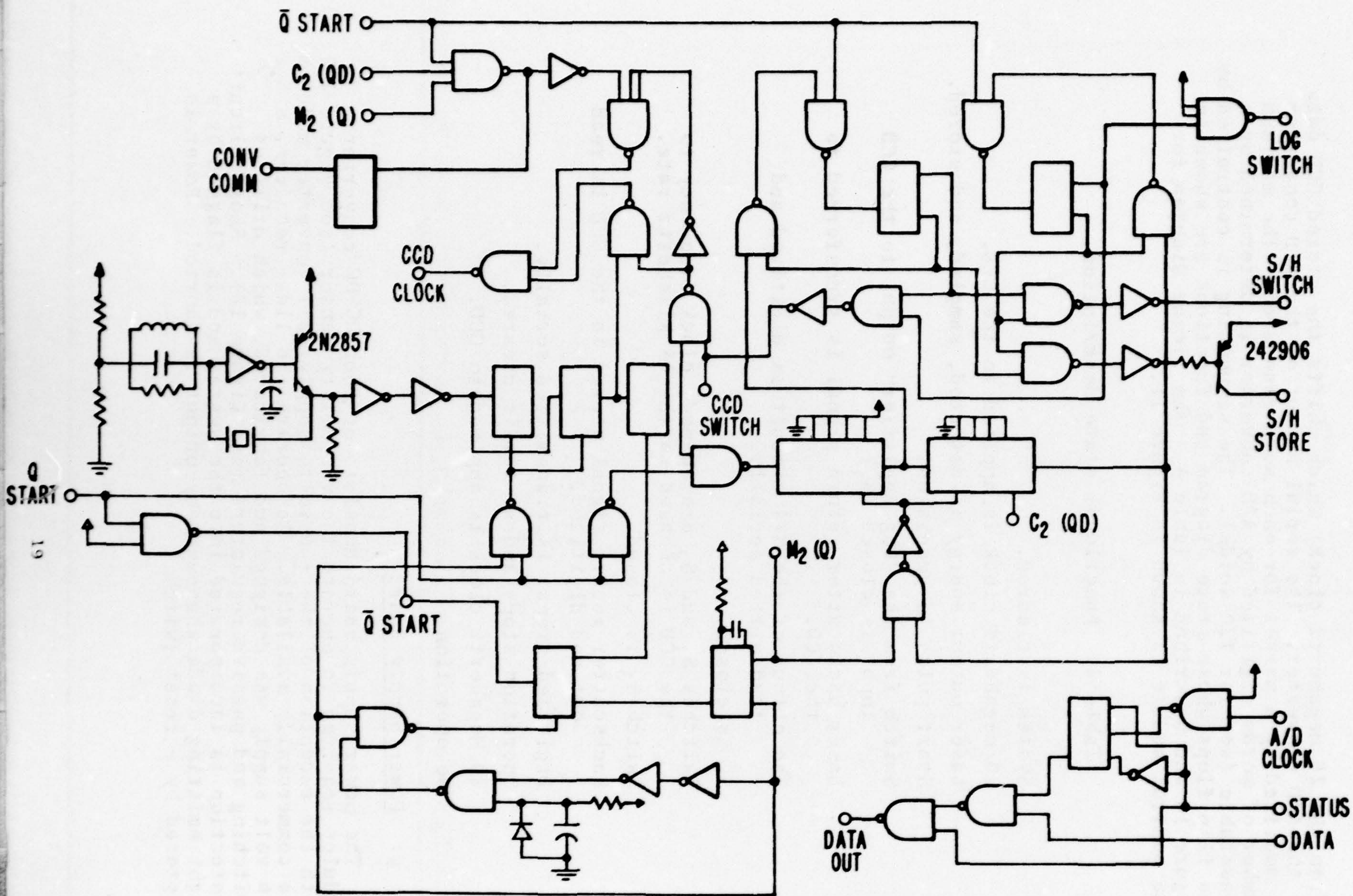

FIGURE 9 CONTROL MODULE

(from the 20 megahertz clock) which shifts the stored CCD data to the A/D converter. The serial output of the A/D converter is modified by a market for each word generated. The maximum number of words digitized by A/D converter is determined by a monostable (set for 120 words). The sequencing is controlled by two flip-flops whose state diagram and functions are shown in Figure 10 and described in Table 4. The timing diagram for the control module is shown in Figure 11.

Table 4. Functional state description.

System is cleared.

20 megahertz clock is applied to the CCD.

Laser output energy is detected, sampled, and stored.

Start pulse is generated.

Switch from the "Log Amplifier" output to the CCD input is closed (S_1).

Laser backscatter return signal is transferred to the CCD.

The output of the S/4 circuit is digitized and transmitted serially.

S_2 is closed.

Switches S_1 and S_2 are opened, clock frequency to the CCD is changed to the 44 kilohertz rate.

Switch S_3 is closed.

Backscatter return signal stored in the CCD is read out and digitized.

Digitized signal is transmitted serially.

Operation stops and system is cleared.

20 Megahertz clock is applied to CCD.

No operation

g. Power Supply Board

The power supply board consists of four DC-DC converter modules required to operate the visibility sensor (see Figure 12). With the exception of the ± 6 volts supply, all converter modules are commercially available. To operate the lidar receiver, a ± 6 volt supply was designed and fabricated, which utilizes switching and passive regulators (see Figure 13). Short circuit protection is incorporated into the system and is flagged by a light emitting diode whenever any output is shorted. Power is restored by a reset switch.

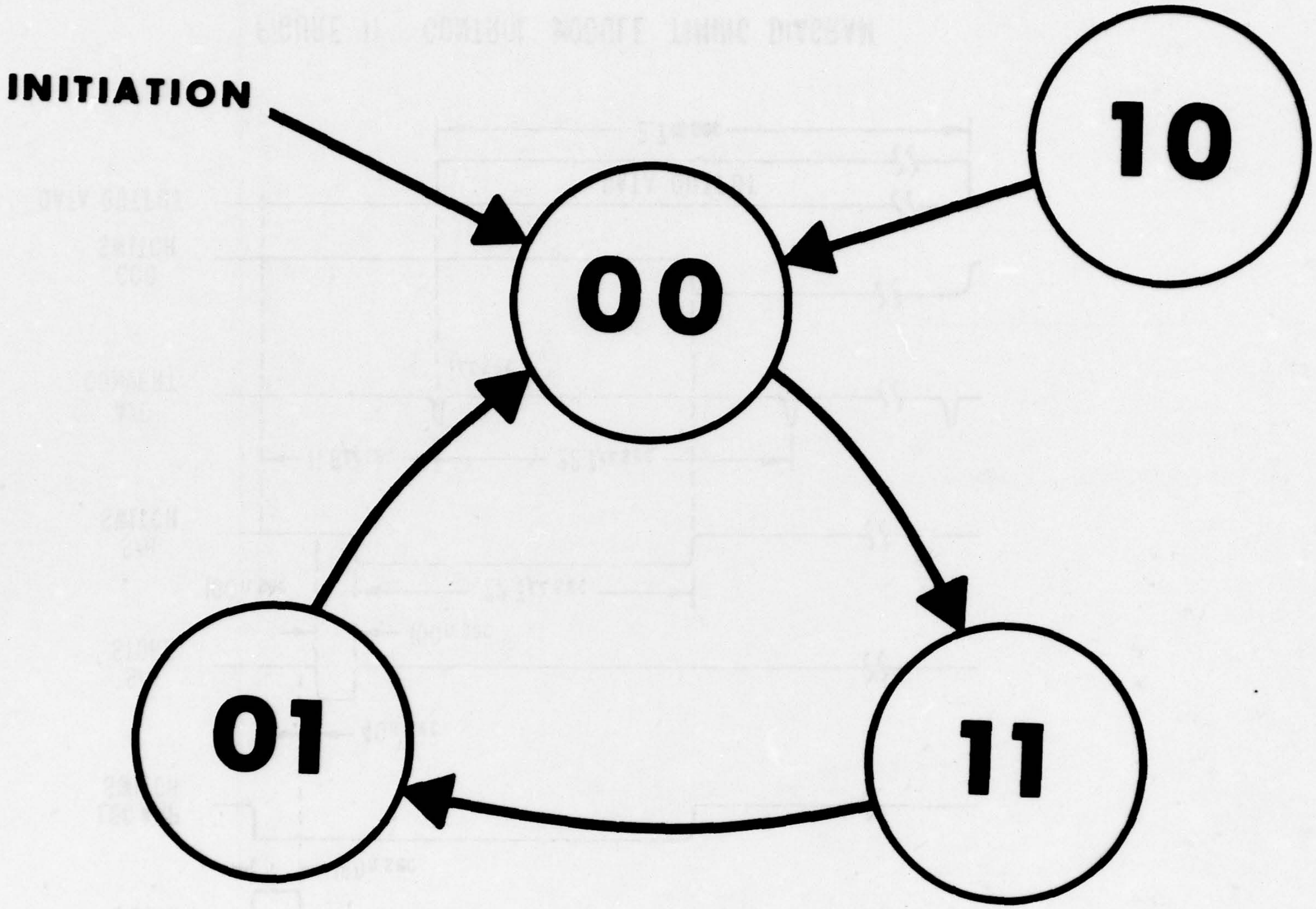

Figure 10. STATE DIAGRAM

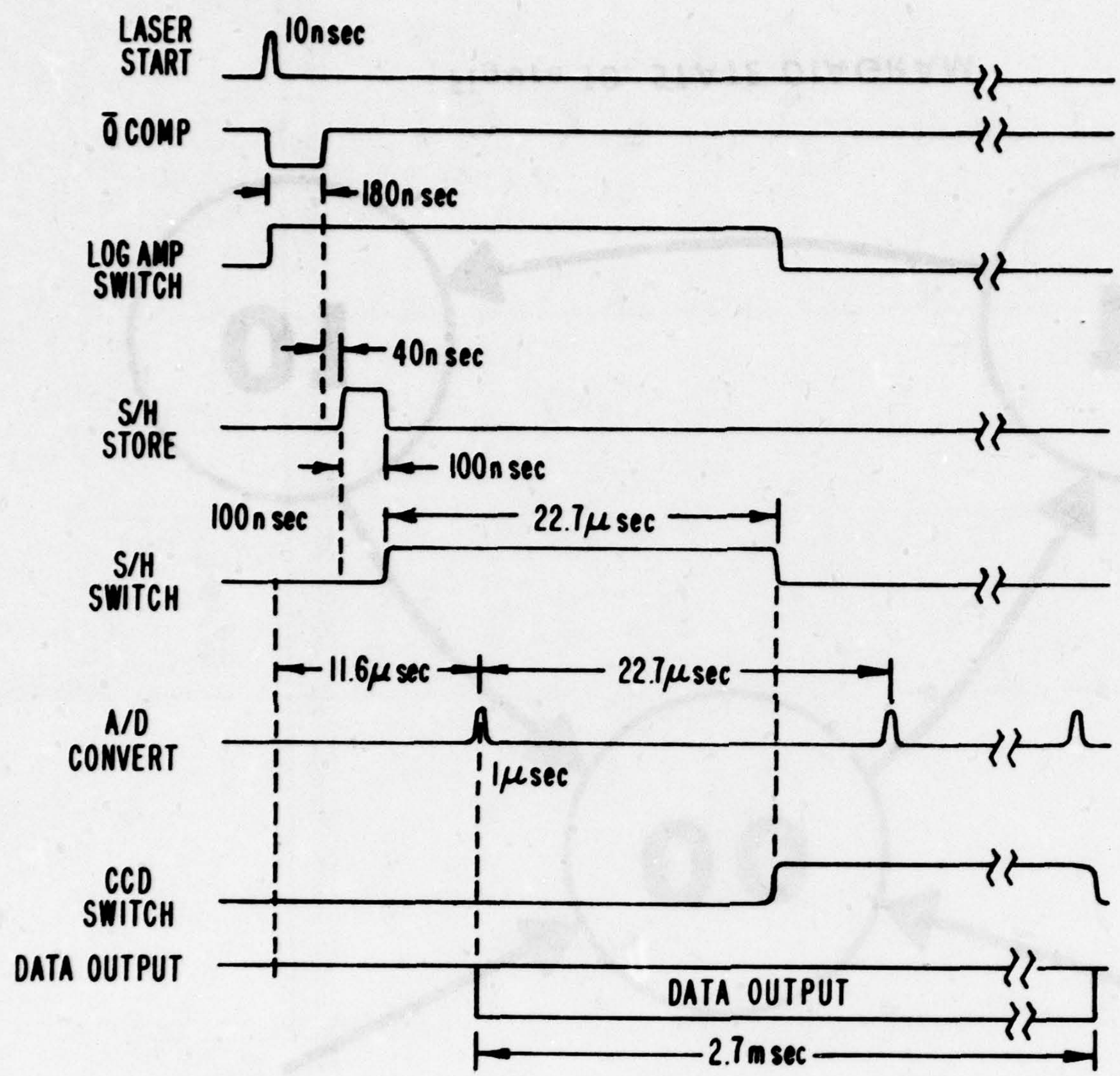

FIGURE 11 CONTROL MODULE TIMING DIAGRAM

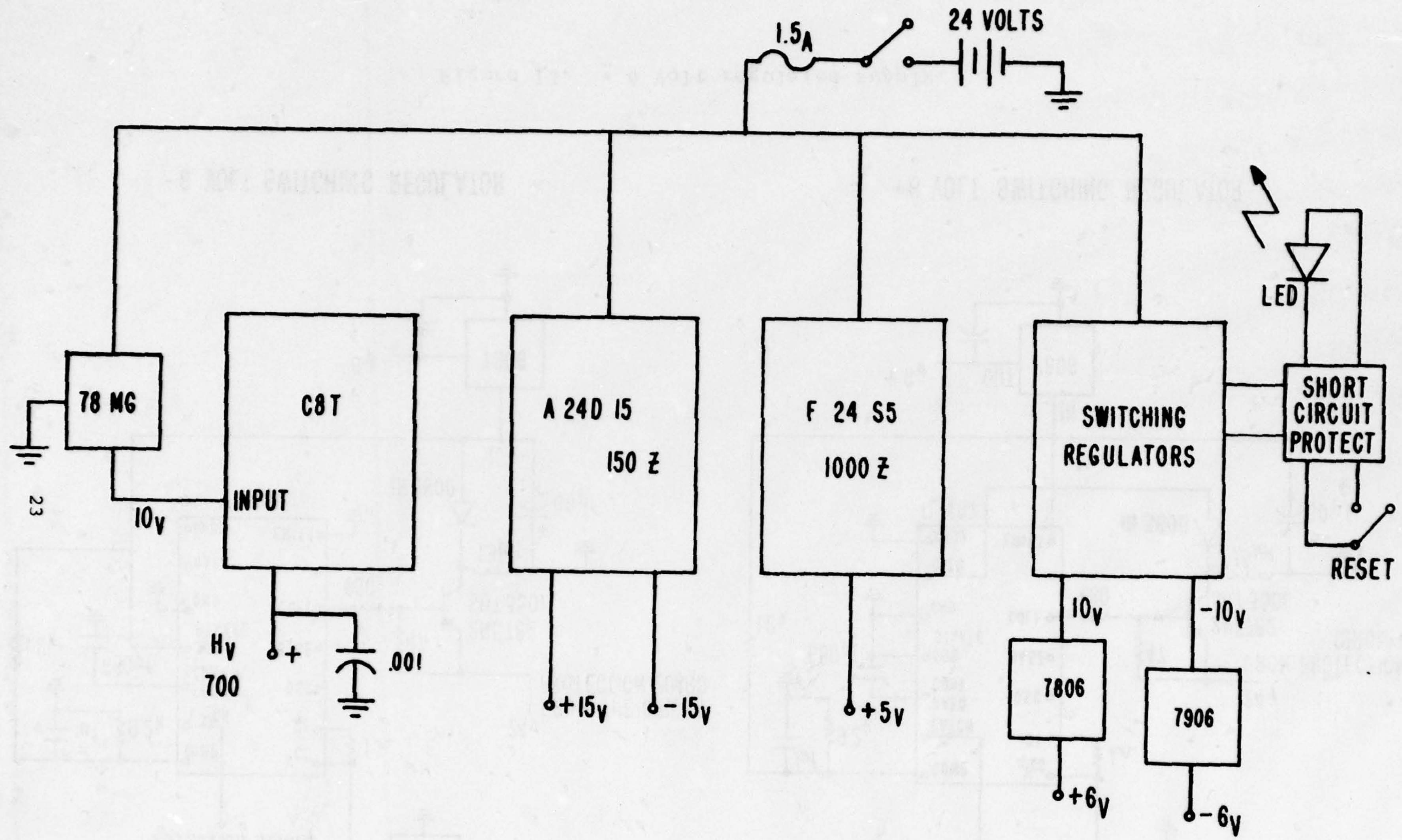

FIGURE 12. POWER SUPPLY BOARD

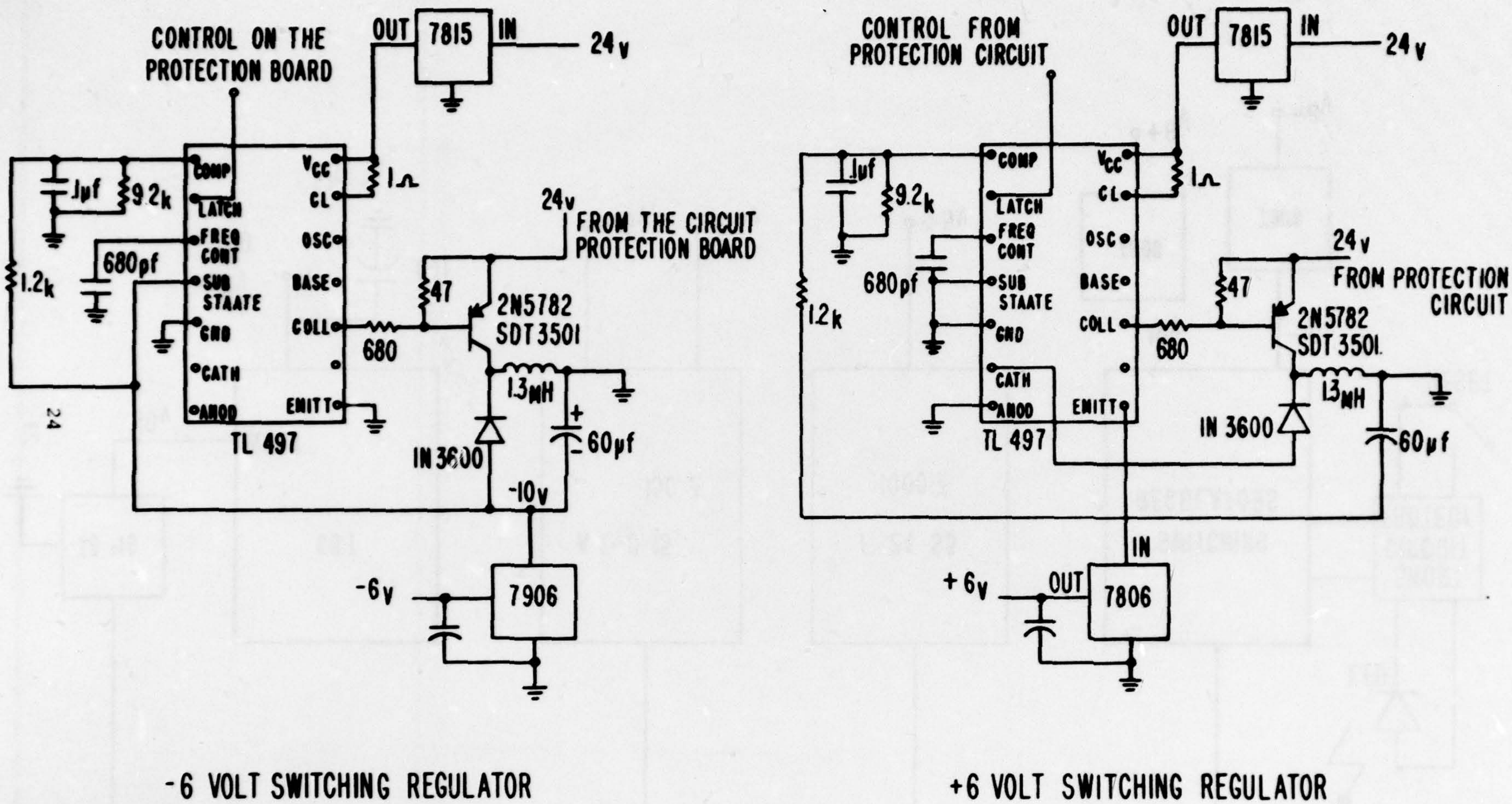

Figure 13. $\pm$ 6 Volt regulated supply.

4. CEILING SENSOR

Ceiling measurements are performed with a direct detection system which determines if the backscattered energy off a cloud base exceeds a set threshold level. This measurement is accomplished with the AN/GVS-5, and is displayed in meters within the sighting optics. Modifications to the minimum range gate and the time programmed gain (TPG) profile of the AN/GVS-5 were required to meet system objectives.

Changing the minimum range gate from 200 meters to 100 meters required replacement of the timing capacitors. The replaced capacitor was mounted on the ceramic substrate of the hybrid range counter module. The time program gain modification was more difficult to implement than the minimum range gate change. The TPG circuit in the AN/GVS-5 is a part of the hybrid videoamplifier module. Its timing is controlled by a proper biased field effect transistor, a thick film resistor, and a capacitor.

The resistor value was increased by carefully scraping off the thick film while observing the TPG output. To finalize the TPG change, the timing capacitor was replaced.

5. TEST RESULTS

a. General

The testing method used to determine the response function of the ceiling and visibility sensors consists of separately determining the individual response functions, and to combine the responses to describe the expected system performance. These tests included measurements of the TPG profile, minimum range, detector-preamp module, log amplifier and CCD module operating characteristics.

b. Ceiling Sensor

The modification to the minimum range gate (AN/GVS-5 counter module) was verified by ranging to targets placed at 100 meters. In addition, the TPG profile of the AN/GVS-5 video amplifier module was modified to minimize the effects of precipital backscatter during ceiling measurements. Data is presented showing the TPG profile before and after modification (see Figure 14). In this application, the range for maximum gain (full sensitivity) was increased, and the slope of gain change was decreased. An example of scattering due to precipitation when ranging to the clouds is shown in Figure 15.

c. Visibility Sensor

The responses of the detector-preamp module, log amplifier and CCD were determined from measurements of the typical

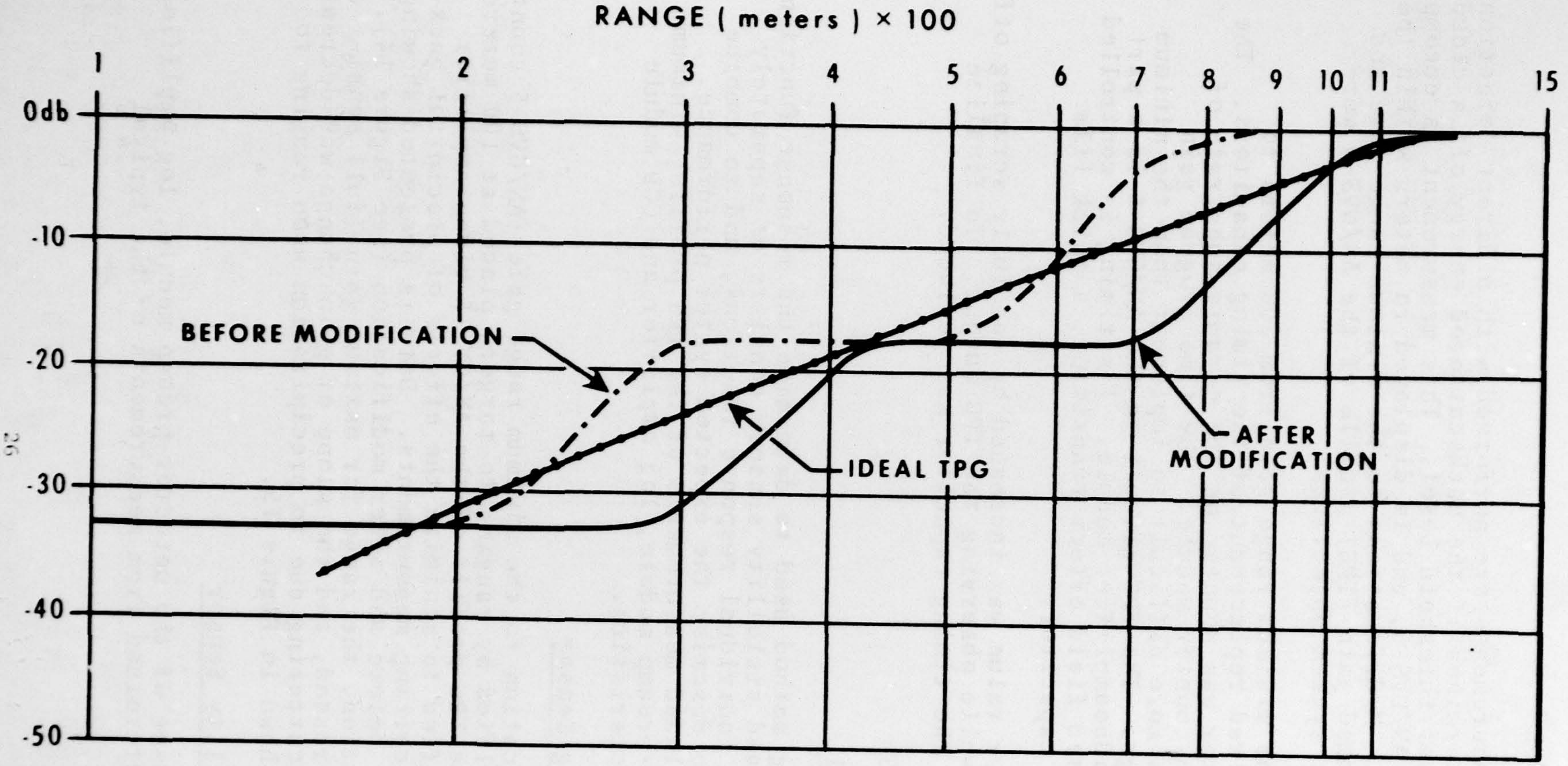

Figure 14. TPG PROFILE OF THE AN/GVS-5 VIDEO AMPLIFIER

electrical characteristics (gain, bandwidth, and CCD module insertion loss). In addition, detector-preamp module linearity and log amplifier transfer characteristics were measured to determine overall system response. Shown in Figure 16 is the detector-preamp module responsivity as a function of temperature. An apertured laser designator was used to measure room temperature responsivity; while a 1.06 micron Light Emitting Diode (LED) was employed in measuring the response (droop) to a long optical pulse (this was calculated to be 150 Hertz). To fully characterize the system response, the module linearity was measured. This test utilized the AN/GVS-5 transmitter module for a source, a diffuse target and a radiometer which measured the power density at the detector-preamp module. The output signal voltage as a function of irradiance is shown in Figure 17. From this graph, a 10% deviation from linearity occurred at an incident power level of 25 microwatts.

Log amplifier tests included measurements of: (1) bandwidth, (2) noise voltage, (3) transfer characteristics, and (4) response to a simulated backscatter return. The bandwidth was measured with a low level signal input, thus preventing any distortion which would effect the actual result. A true rms voltmeter was used to measure the output noise voltage. These measurements are listed in Table 5.

Table 5. Log amplifier characteristics.

Low-level signal gain	33 dB
Equivalent input noise voltage	0.2
Bandwidth	>30 MHz
Maximum input signal level	3.2 V
Maximum output signal	2.1 V

The transfer characteristics (voltage gain as a function of input were measured (see Figure 18). From this data an equation which characterizes the behavior of the log amplifier was derived. This was determined by calculation of the slope of the gain roll-off and fitting to the general equation by:

$$A = B/(1 + C^n)^{\frac{1}{2}}$$

where $A = Vsout$

$B = 44.67\ Vsin$

$C = Vsin/0.0317$

$n = 1.8$

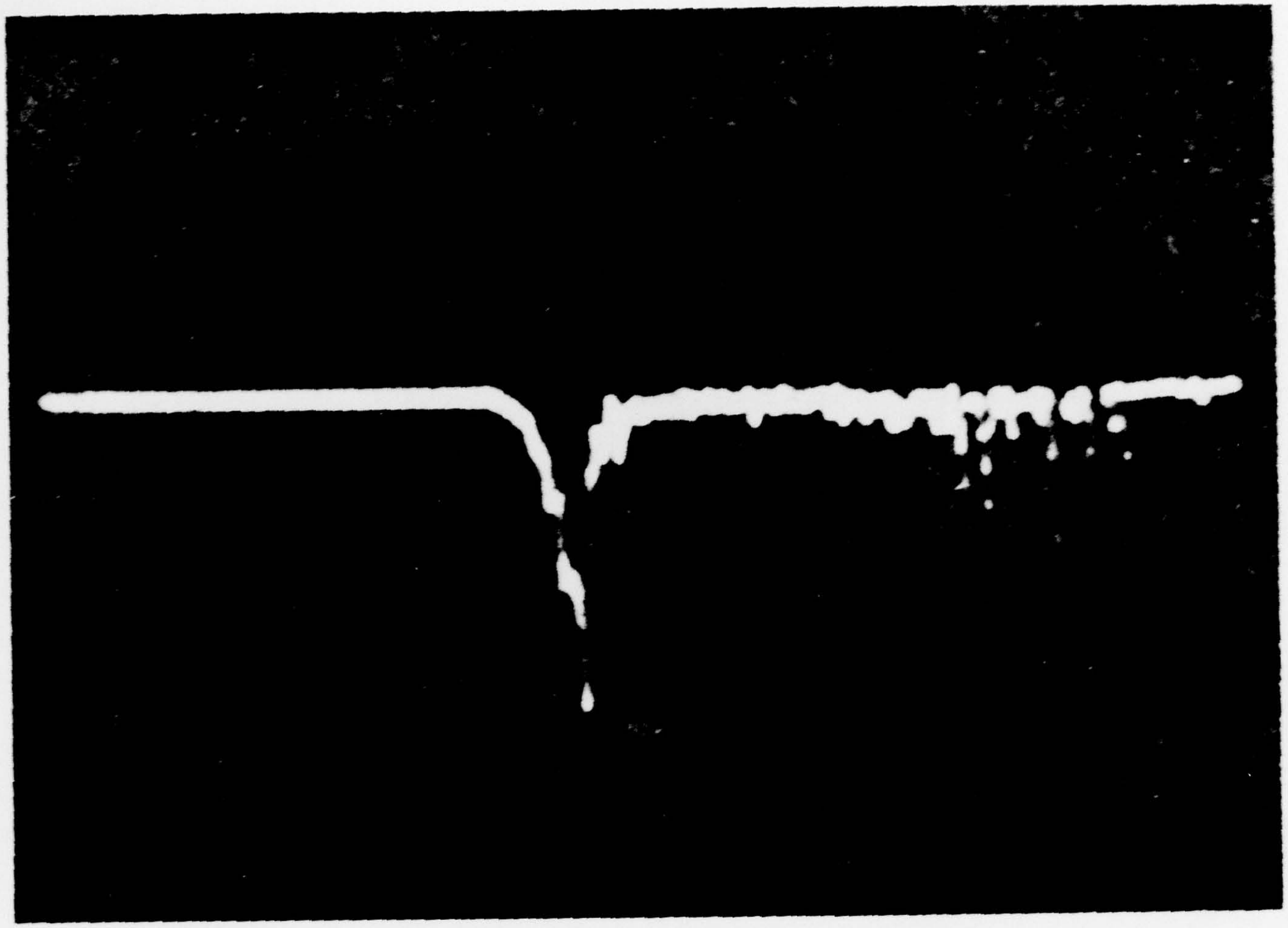

Figure 15. Backscatter return with precipitation present.

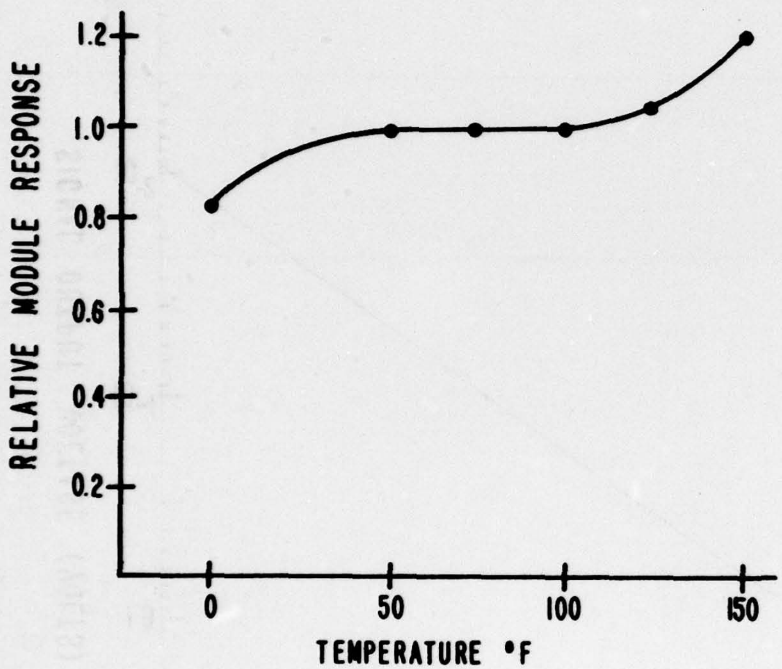

FIGURE 16 DETECTOR - PREAMP RESPONSIVITY AS FUNCTION OF TEMPERATURE

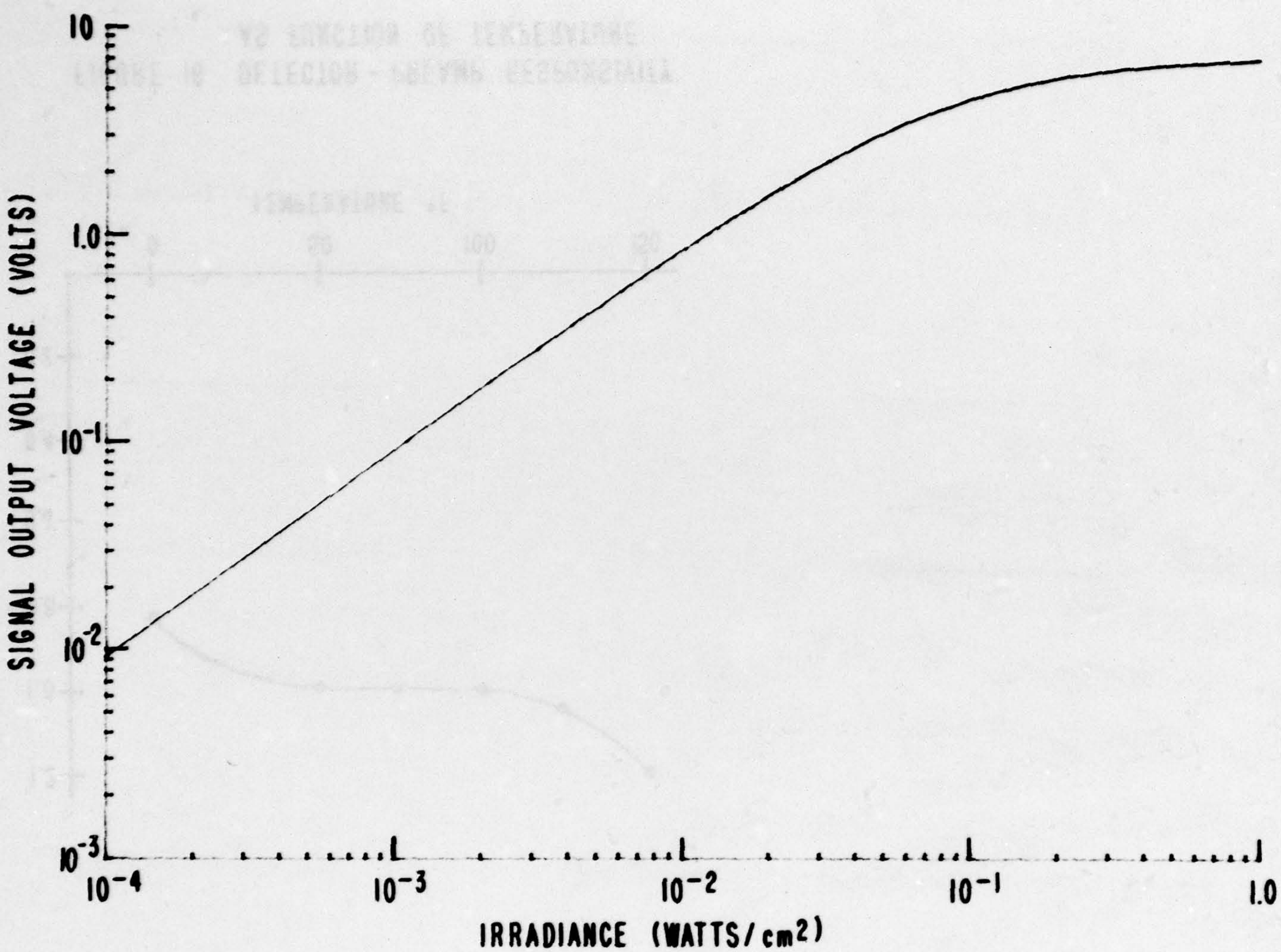

FIGURE 17. DETECTOR - PREAMP MODULE RESPONSE

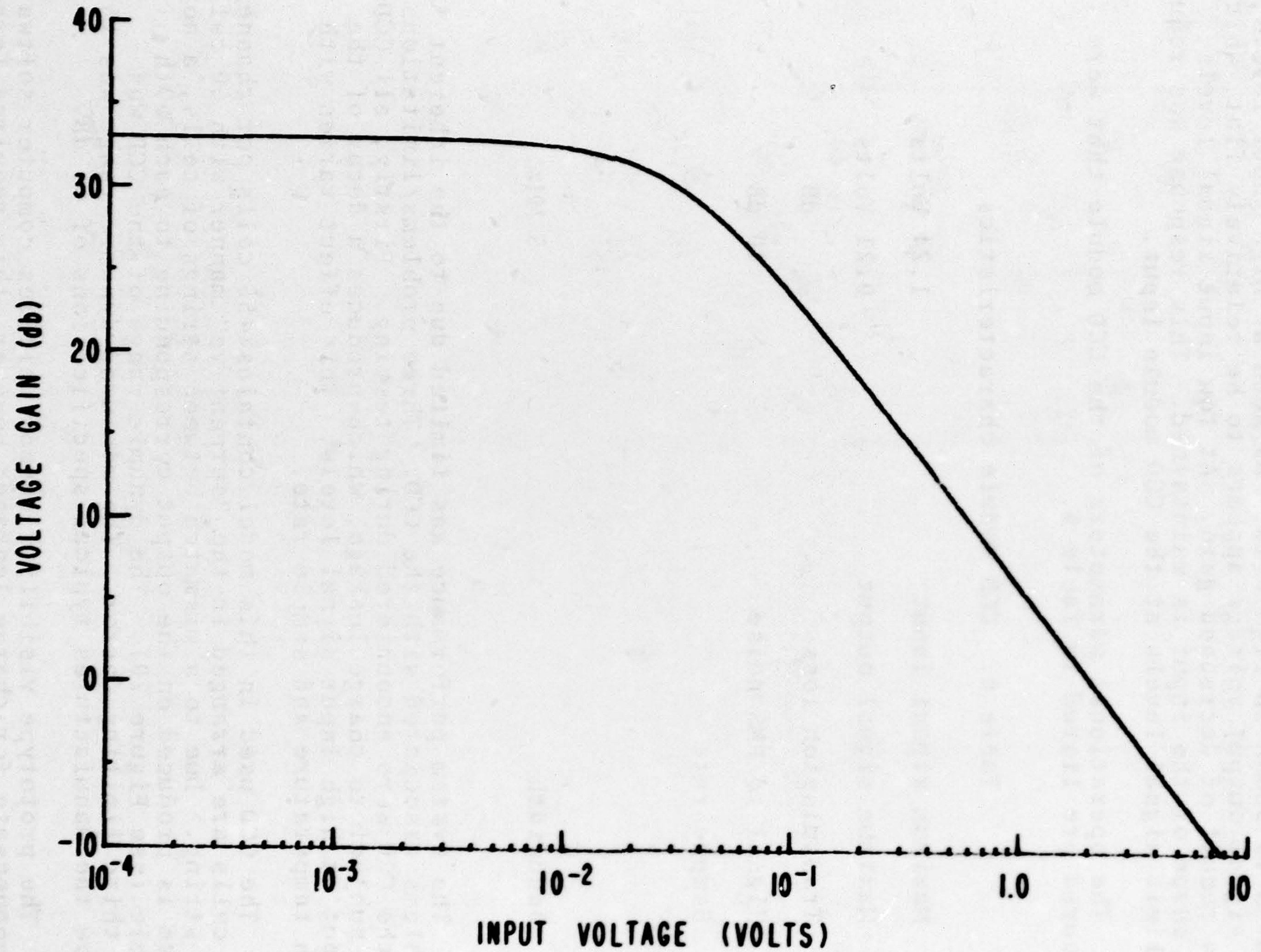

Figure 18. Log amplifier transfer characteristics.

The log amplifier response to two simulated backscatter returns is shown in Figure 19. As seen at high input levels, the signal output voltage appears to be relatively flat, which is a result of decreased gain. At low input signal levels, the shape of the input is maintained. This response was required to limit signal levels at the CCD module input.

The operational parameters of the CCD module that were measured are listed in Table 6.

Table 6. CCD Module characteristics.

Maximum signal input	1.24 Volts
Maximum signal output	0.21 Volts
Transmission loss	dB
Signal to RMS noise	40 dB
Sample rate	
Bandwidth	5 MHz

The system performance was limited due to the inherent problems associated with the CCD. Three problems/limitations of the CCD were encountered during testing. Firstly, all CCDs are subject to charge leakage, which produces a decay of the output at high input signal levels. This effect varies with both temperature and sample rate.

The CCD used in this model contains 455 cells per channel. The cells are arranged in the "serpentive" manner with 60 cells per string. Due to a mismatch between strings of cells, a noise pulse is produced on the output corresponding to each 60th sample (see Figure 20). The dynamic range of the CCD was the third limiting factor. The measured dynamic range was 15 dB below the manufactures typical specifications of 55 dB.

The prototype visibility sensor utilizes computer software to compensate for charge leakage; however, this requires large computer time and memory. Improvements may be accomplished by nullifying the charge leakage.

Characterization of the system is further complicated by nonlinearity of the series analog switches. The transfer characteristics of the simple analog switch is given by:

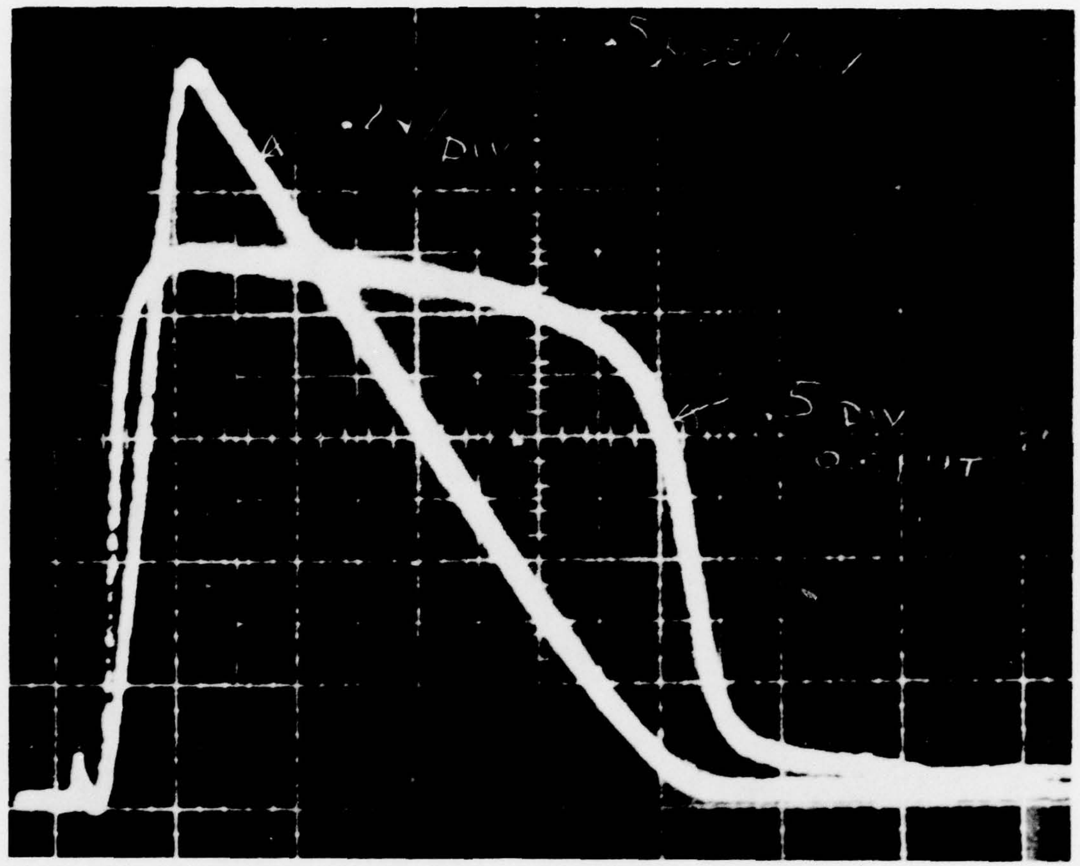

Figure 19(a). Log amplifier response to a simulated backscatter return.

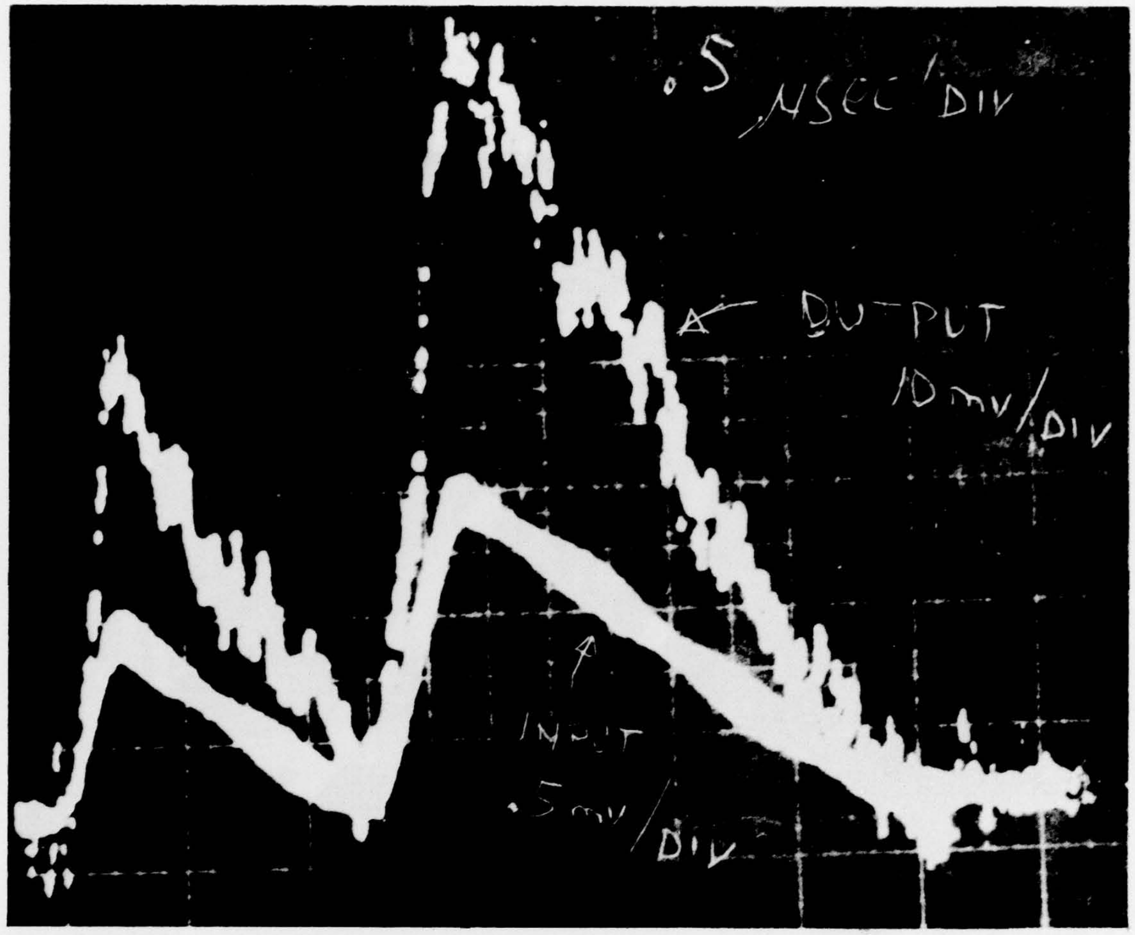

Figure 19(b). Log amplifier response to a simulated back-scatter return.

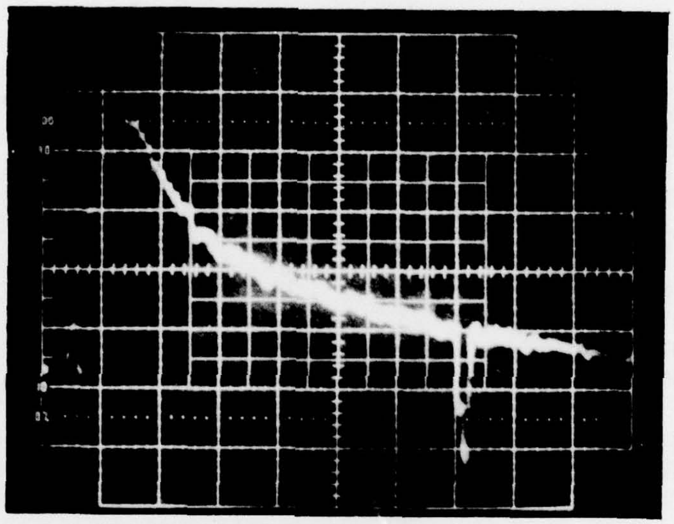

Figure 20. CCD Noise pulse.

$$V_{out} = 2.52\,V_{in}(V - 0.38\,V_{in})(1 - 0.25\,V_{in}(V - 0.38\,V_{in})/V^2/V^2$$

where V_{in} = Preamp. detector output

V_{out} = A/D converter input

$$V = \left[1 + (V_{in}/0.0317)^{1.8}\right]^{0.5}$$

Given that the A/ D converter output is given by $(2^{12})V/5$, the total system response can be calculated. Shown in Figure 21 is the total system response (transfer function) as a function of signal power level.

6. CONCLUSIONS

A prototype single-ended visibility and ceiling meter has been fabricated and tested at Otis Air Force Base, Falmouth, MA. While the feasibility of utilizing the AN/GVS-5 Laser Rangefinder had been previously established, modifications to the minimum range gate and TPG were required to satisfy test conditions. The major area of concern was the ability to extract useful lidar backscatter data using a single, low energy laser pulse (AN/GVS-5 transmitter module). Use of a sensitive receiver (temperature compensated silicon avalanche detector-preamp module), log amplifier and a CCD module provided the means of detecting and expanding the lidar backscatter return for analysis. Implementing this approach has resulted in obtaining useful backscatter data at ranges in excess of 800 meters (approximately 1 km visibility). The overall system capability was limited by the CCD module noise and dynamic range capability. The detector-preamp module is capable of responding to variations in signal levels of six orders of magnitude or greater. The CCD module (utilized in the prototype model)was capable of 40 dB dynamic range (maximum signal to rms noise). Incorporating recent improvements in CCD technology should result in improved system accuracy. In addition to lidar backscatter measurements, ceiling measurements were obtained with the visio-receiver. This eliminates the requirement for two receiver channels; thereby reducing complexity and cost. Since the prototype unit (without mini-computer) was tripod mounted; ceiling, slant and horizontal lidar backscatter returns were obtained with relative ease. The problems associated with eye safety are decreased with the low output energy used in the system. As a result of this effort, a program has been initiated that will utilize a single receiver channel and micro-computer to perform the equivalent functions.

In summary, concept and feasibility of a visioceilometer has been successfully established. Technology requirements, as far as laser and laser related electro-optics are concerned, are of low risk. Therefore, in view of the desirability of

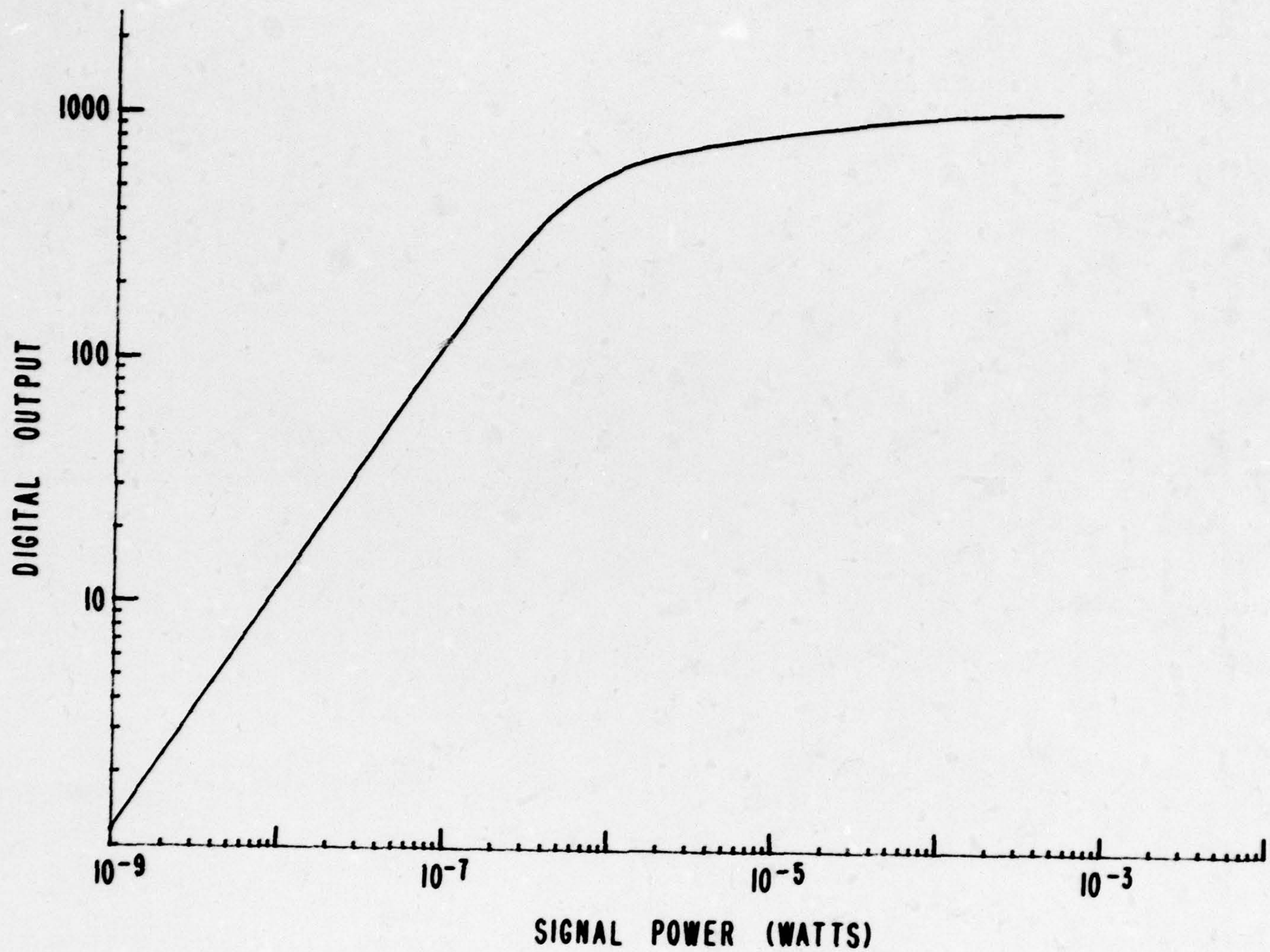

FIGURE 21. PREDICTED SYSTEM RESPONSE

such an item on a DOD-wide basis, development of a visioceilometer towards an early fielding should be aggressively pursued.